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Takeo et al.

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(54) **HIGH-FREQUENCY OSCILLATION DEVICE, MAGNETIC RECORDING HEAD INCLUDING THE SAME, AND DISK DEVICE**

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G11B 5/127 (2006.01)

(52) **U.S. Cl.**
CPC ***G11B 5/127*** (2013.01)

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USPC 360/125.3, 125.03, 125.31, 125.04, 360/125.09, 125.12, 125.17, 125.16
See application file for complete search history.

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(74) *Attorney, Agent, or Firm* — Patterson & Sheridan, LLP

(57) **ABSTRACT**

A magnetic recording head includes a main magnetic pole that applies a recording magnetic field to a recording layer of a recording medium, a write shield that faces the main magnetic pole with a write gap therebetween, a recording coil that generates a magnetic field in the main magnetic pole, a high-frequency oscillator that includes a field generation layer and a spin injection layer, and is disposed within the write gap between the main magnetic pole and the write shield, a wiring electrically connected to the high-frequency oscillator, a modulation electrode that applies a modulation voltage to the field generation layer, and a modulation insulating layer that is interposed between the field generation layer and the modulation electrode.

19 Claims, 17 Drawing Sheets

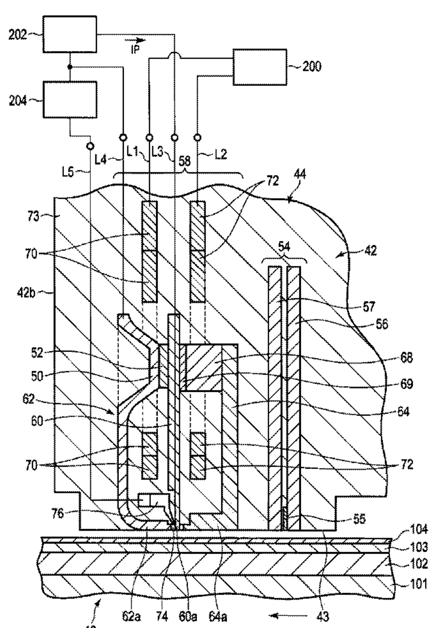


FIG. 1

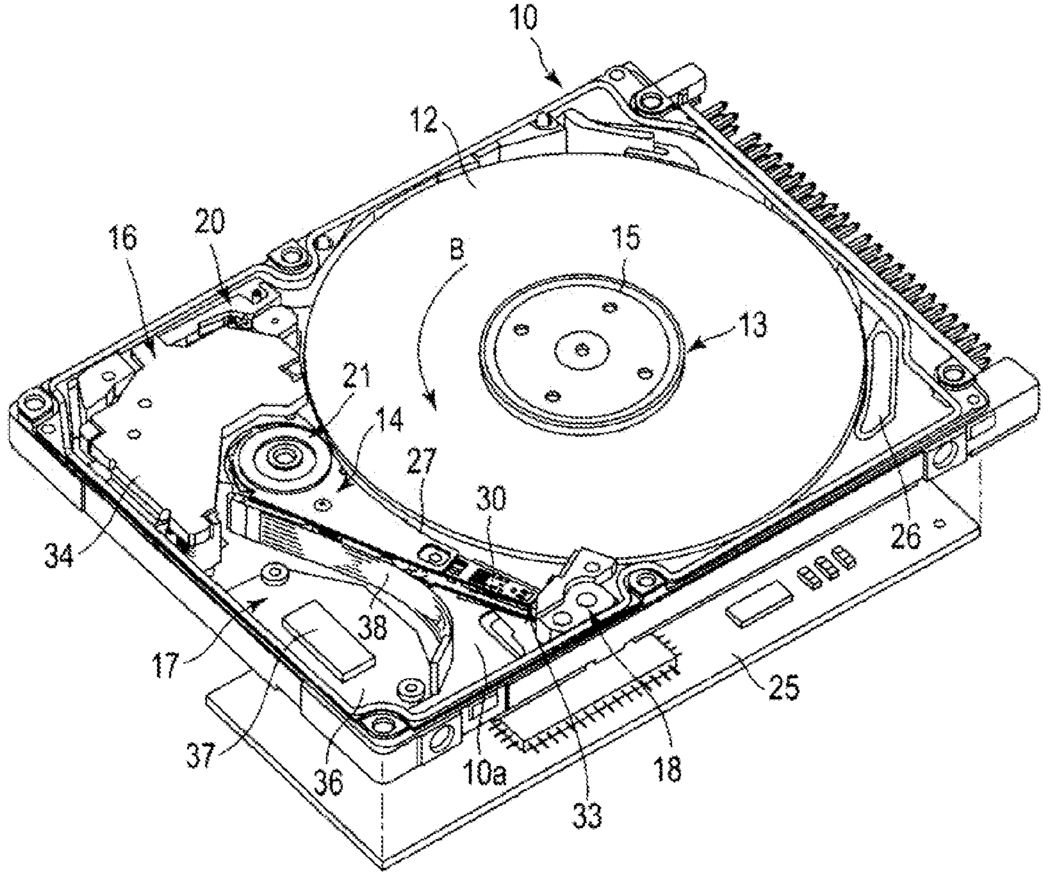

10
12
16
20
15
B
13
21
14
27
30
34
38
17
26
25
37
36
10a
33
18

FIG. 2

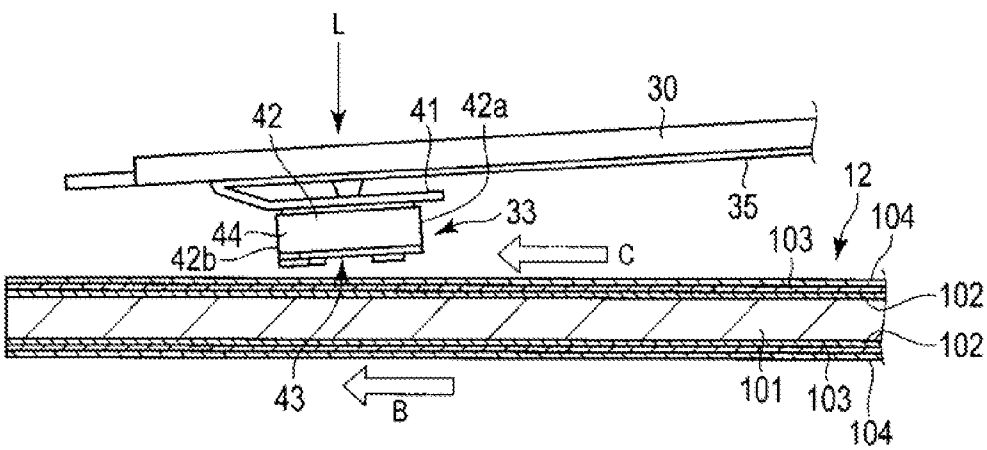

L
30
42
41
42a
35
12
104
33
44
103
42b
C
102
102
43
B
101
103
104

FIG. 3

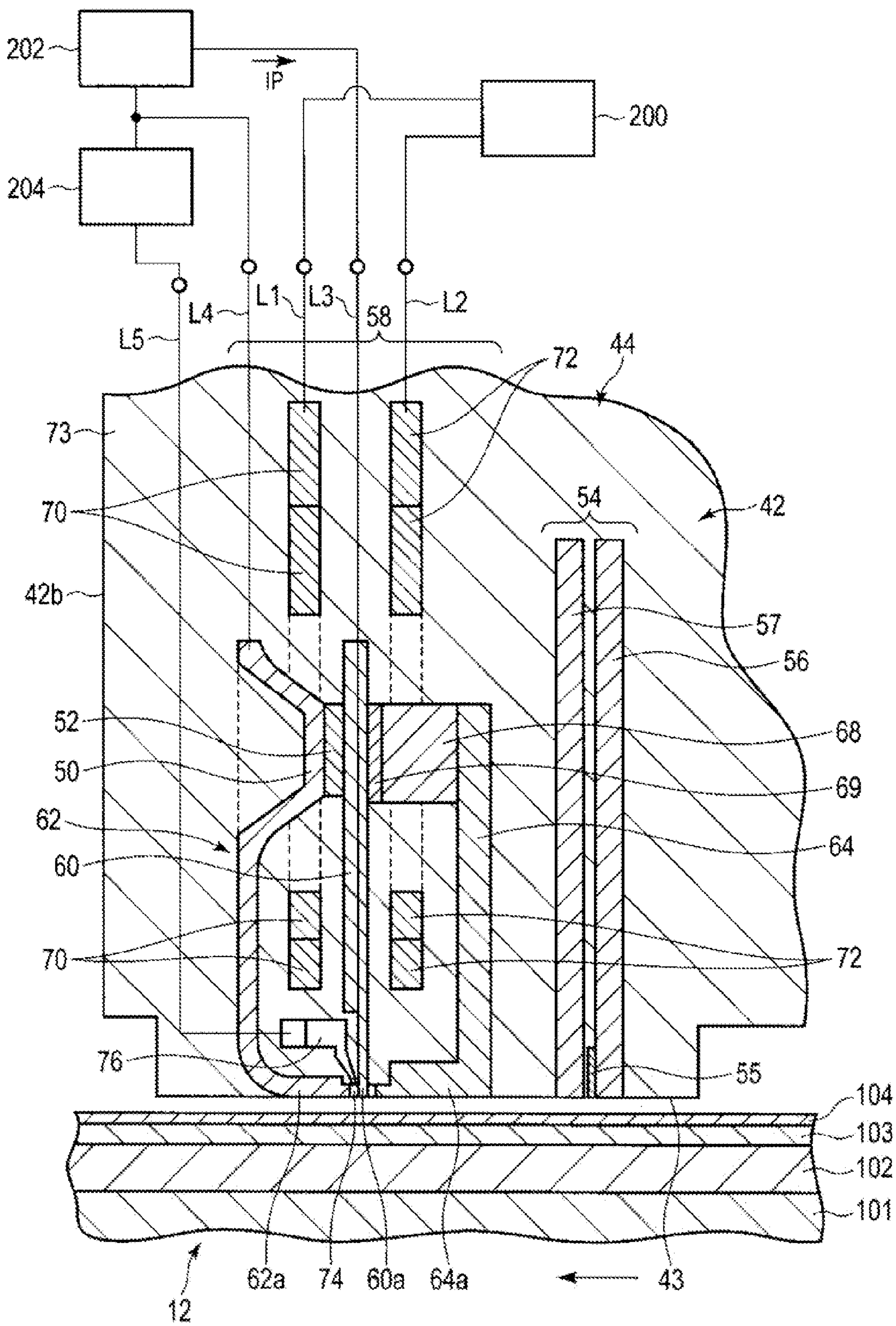
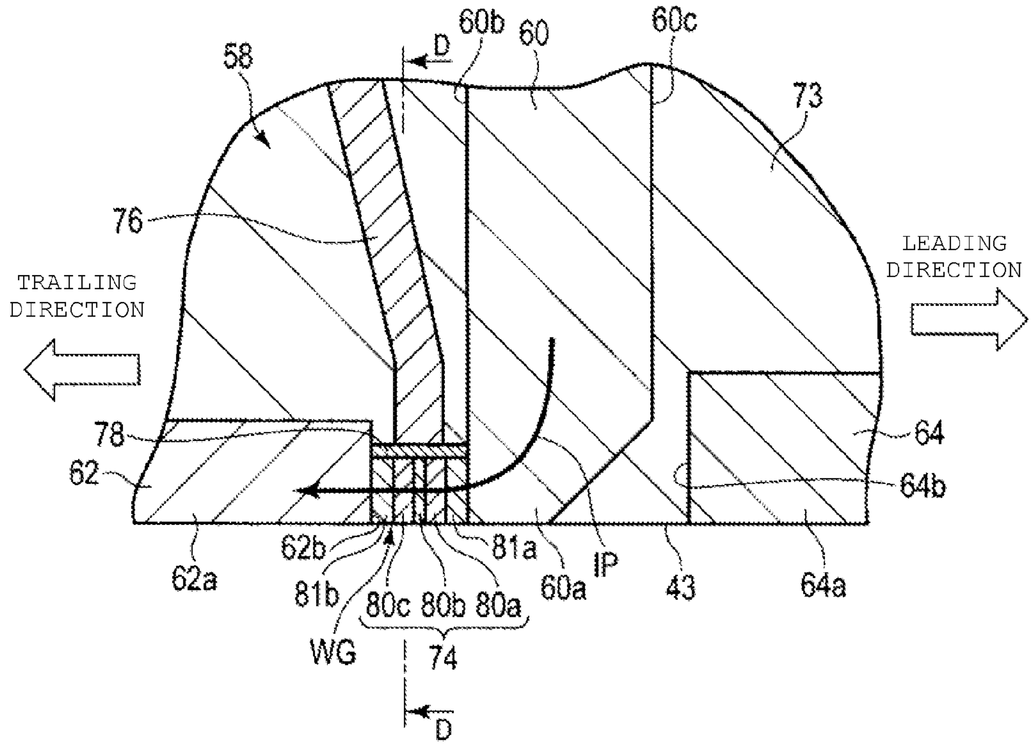
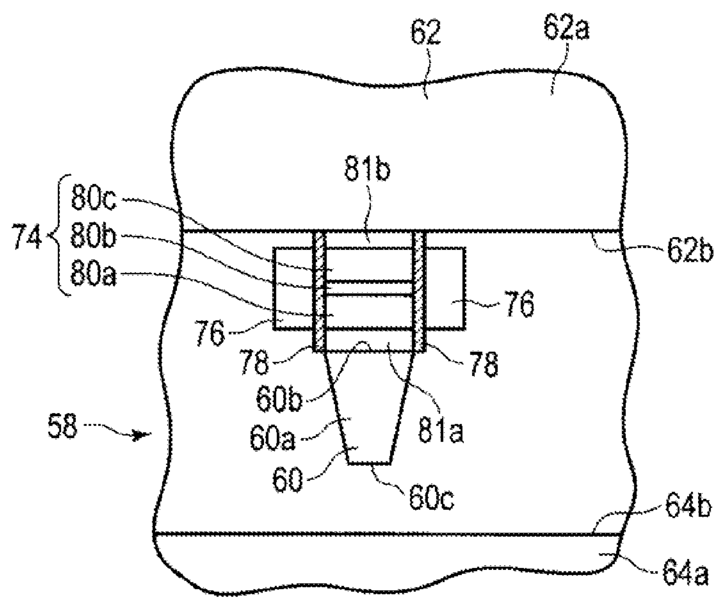

202
IP
200
204
L5
L4
L1
L3
58
L2
44
72
73
70
54
42
42b
57
56
52
68
50
69
62
64
60
70
72
76
55
104
103
102
101
62a
74
60a
64a
43
12

FIG. 4



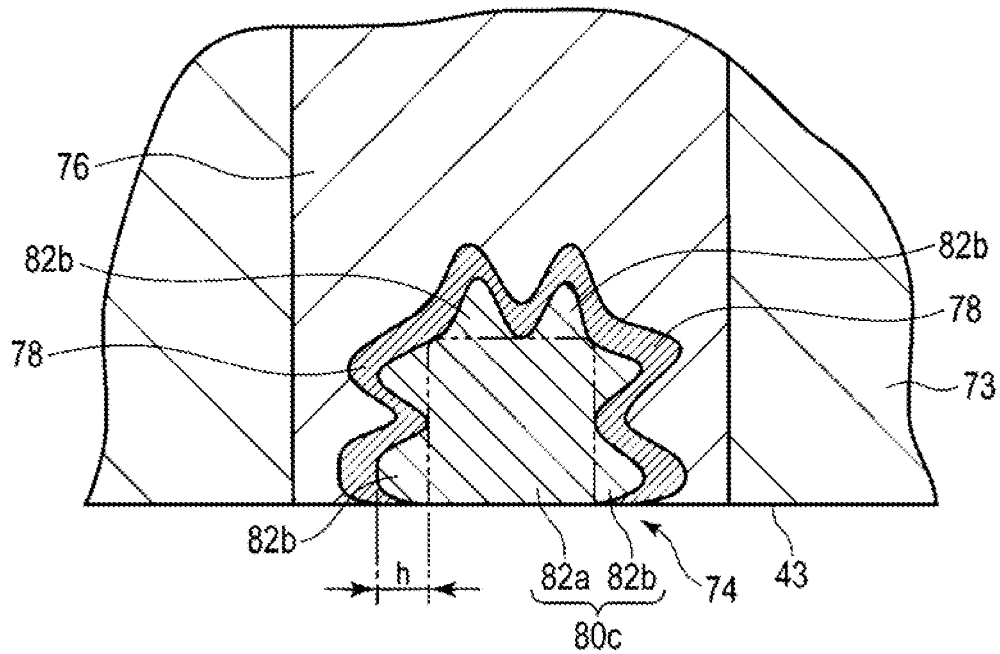
58
60b
60
60c
73
D
76
TRAILING DIRECTION
LEADING DIRECTION
78
62
64
64b
62b
81a
62a
81b
80c
80b
80a
60a
IP
43
64a
WG
74
D

FIG. 5



62
62a
81b
74
80c
80b
80a
62b
76
76
78
78
60b
81a
58
60a
60
60c
64b
64a

FIG. 6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82b
82b
78
78
73
82b
h
82a
82b
80c
74
43

FIG. 7

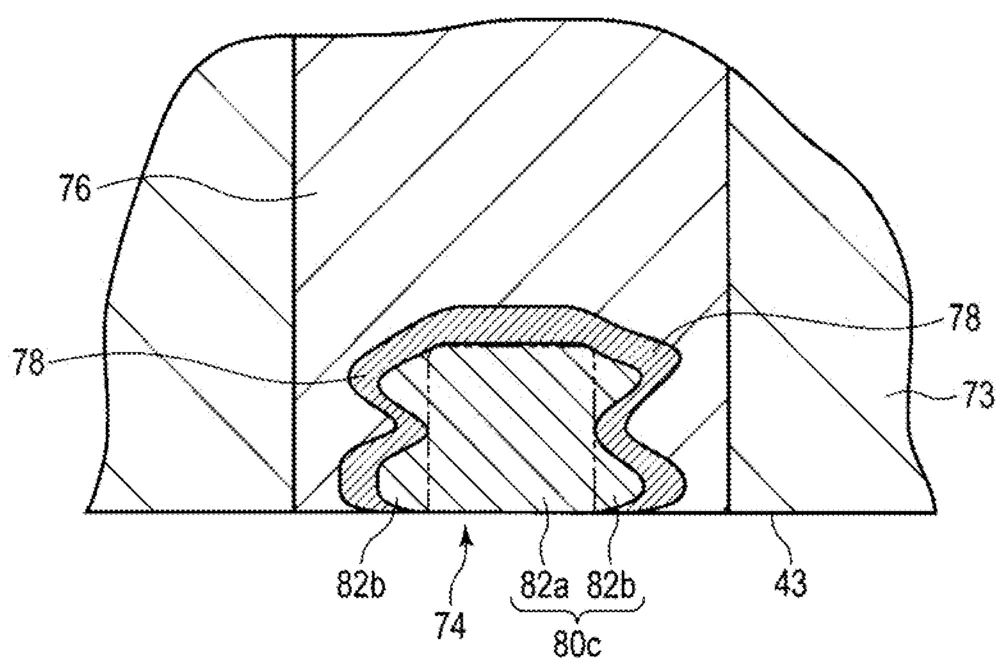
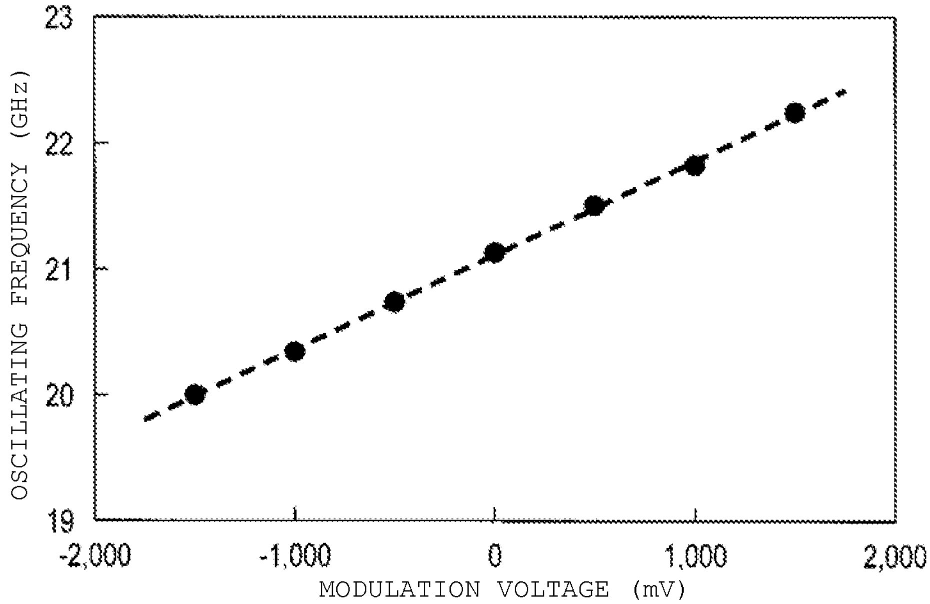
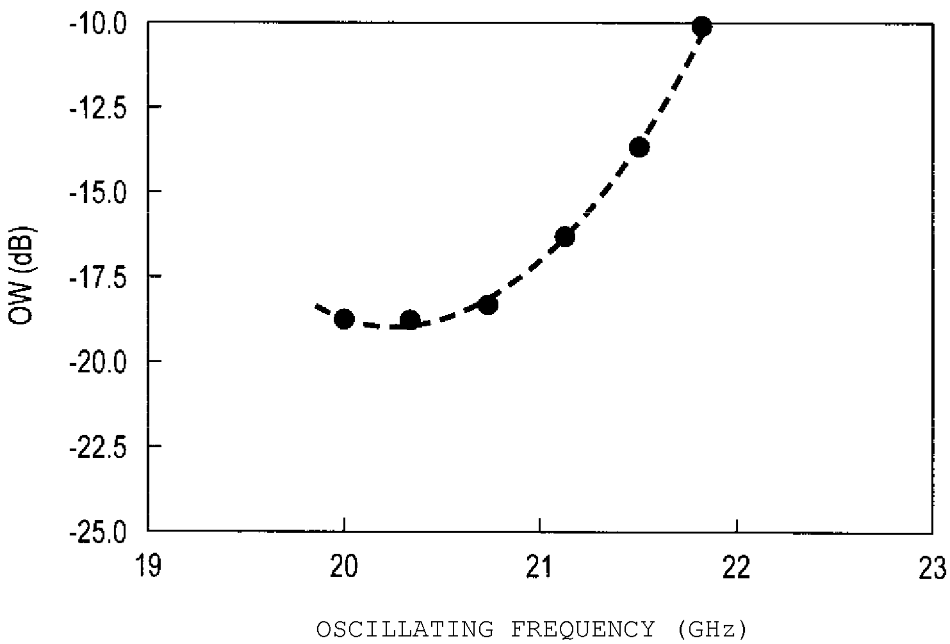

76
78
78
73
82b
74
82a
82b
80c
43

FIG. 8



23
22
21
20
19
OSCILLATING FREQUENCY (GHz)
-2,000
-1,000
0
1,000
2,000
MODULATION VOLTAGE (mV)

FIG. 9



-10.0
-12.5
-15.0
-17.5
-20.0
-22.5
-25.0
OW (dB)
19
20
21
22
23
OSCILLATING FREQUENCY (GHz)

FIG. 10

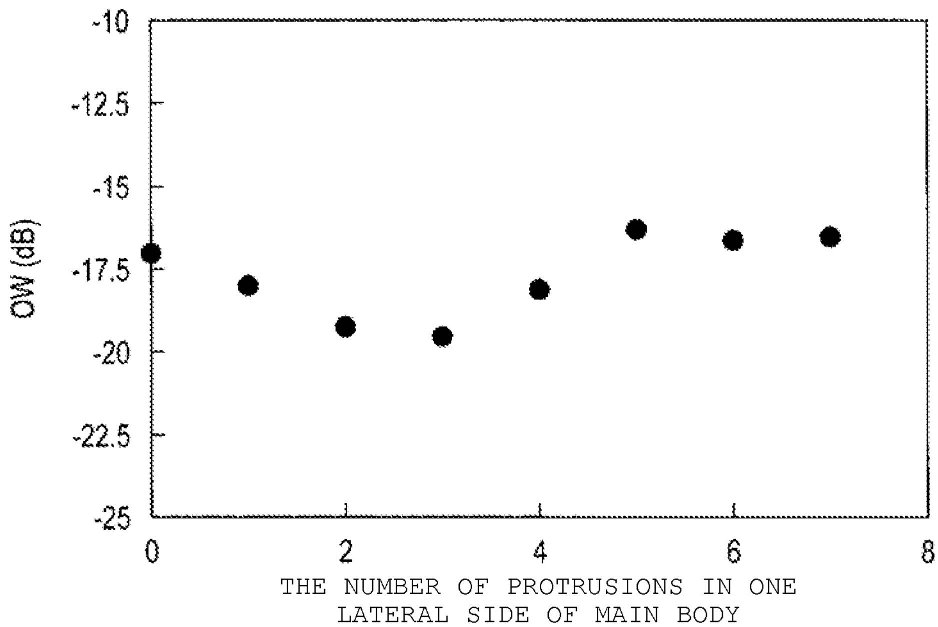

-10
-12.5
-15
-17.5
-20
-22.5
-25
OW (dB)
0
2
4
6
8
THE NUMBER OF PROTRUSIONS IN ONE LATERAL SIDE OF MAIN BODY

FIG. 11

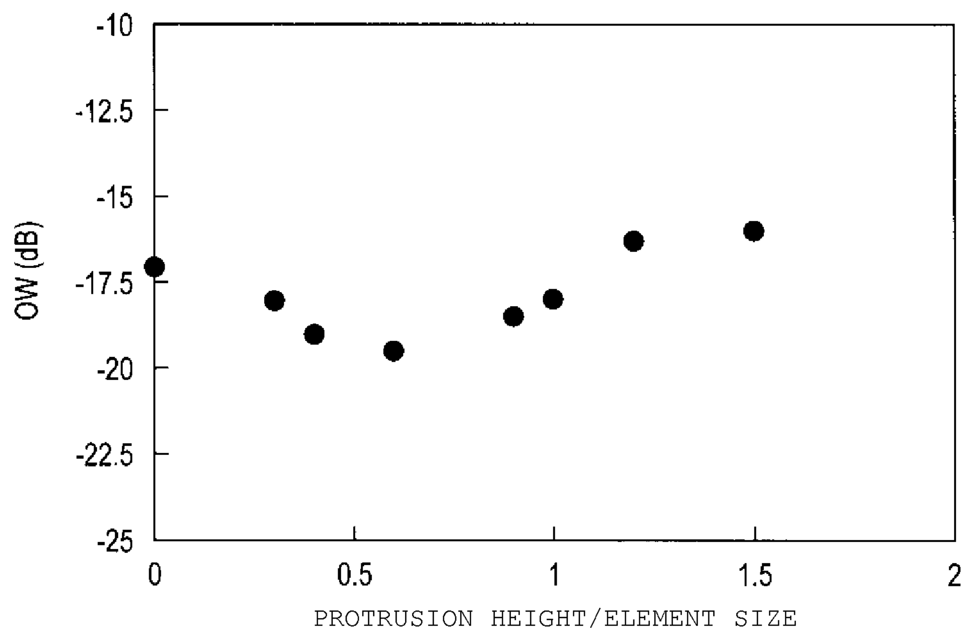

-10
-12.5
-15
-17.5
-20
-22.5
-25
OW (dB)
0
0.5
1
1.5
2
PROTRUSION HEIGHT/ELEMENT SIZE

FIG. 12

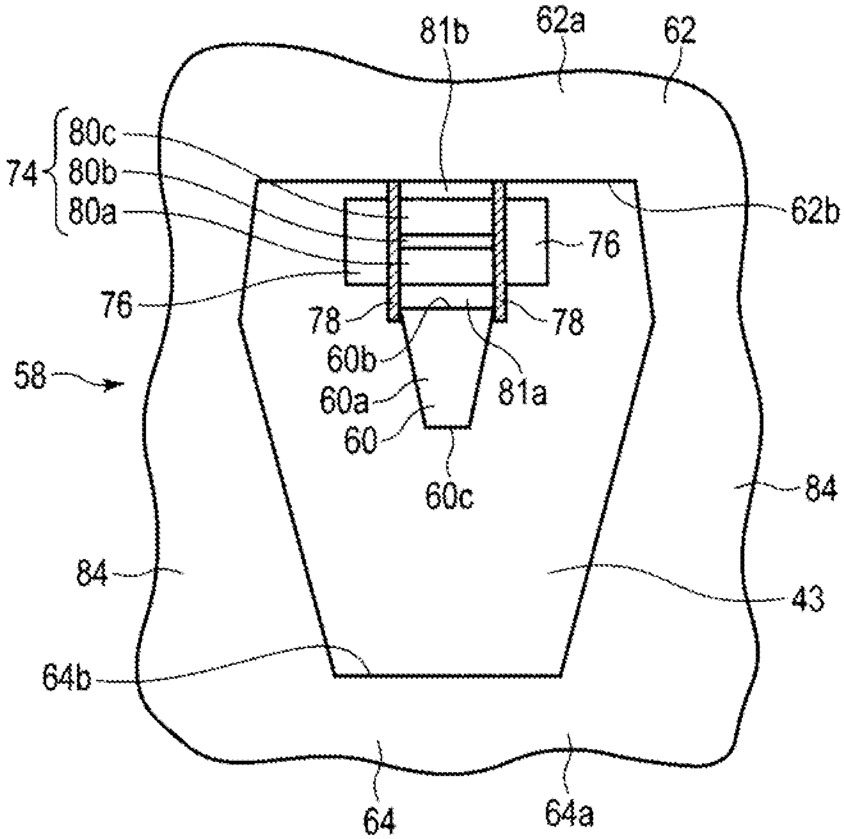
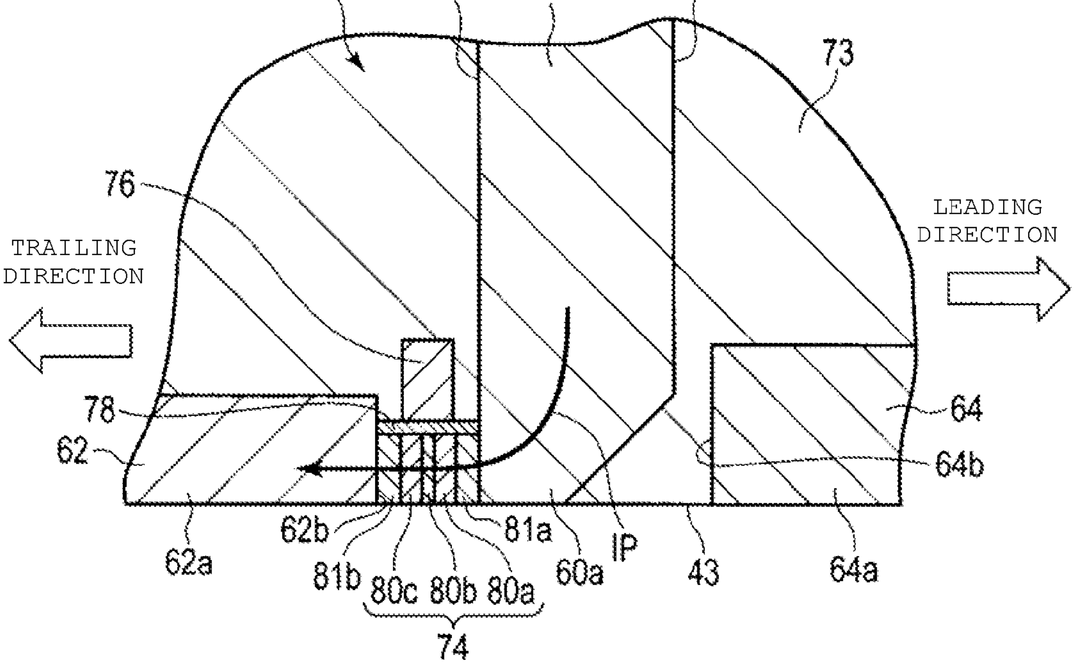

81b
62a
62
74
80c
80b
80a
62b
76
76
78
78
60b
81a
58
60a
60
60c
84
84
43
64b
64
64a

FIG. 13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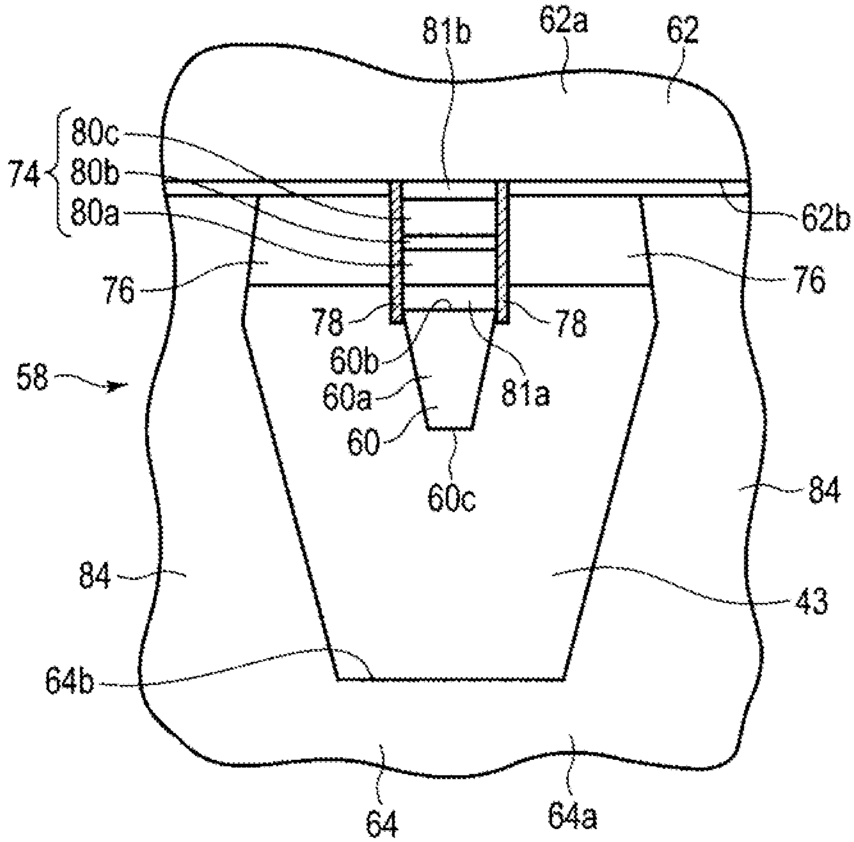
60b
60
60c
73
76
TRAILING DIRECTION
LEADING DIRECTION
78
62
64
64b
62b
81a
IP
62a
81b
80c
80b
80a
60a
43
64a
74

FIG. 14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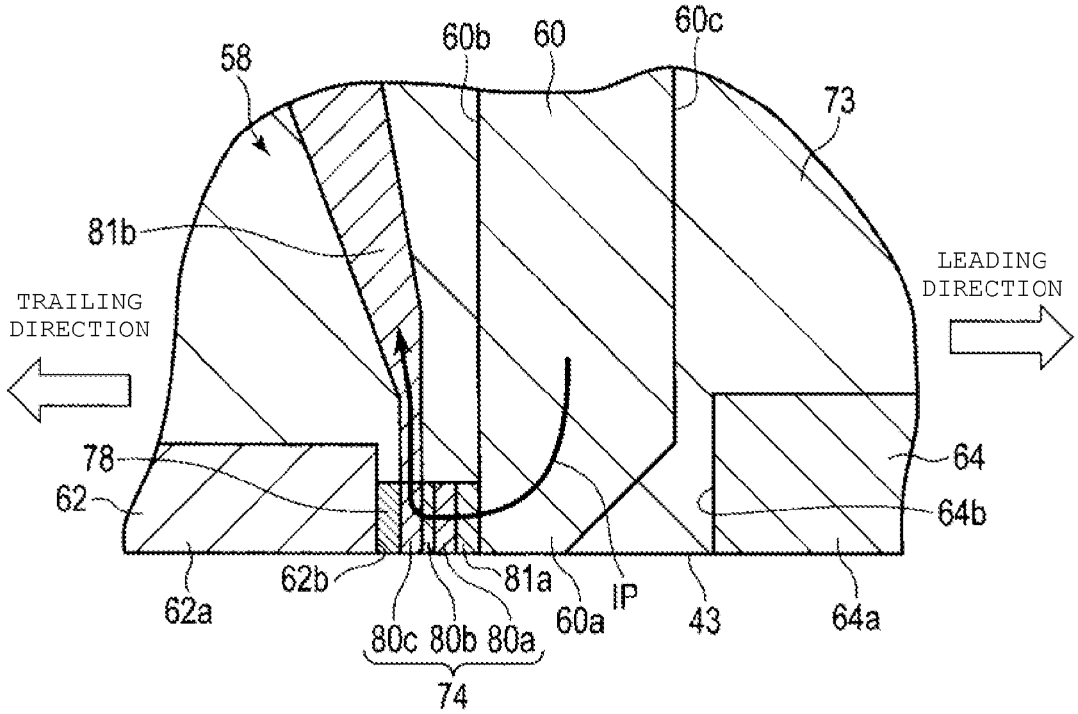
62a
62
80c
74
80b
80a
62b
76
76
78
78
60b
81a
58
60a
60
60c
84
84
43
64b
64
64a

FIG. 15


58
60b
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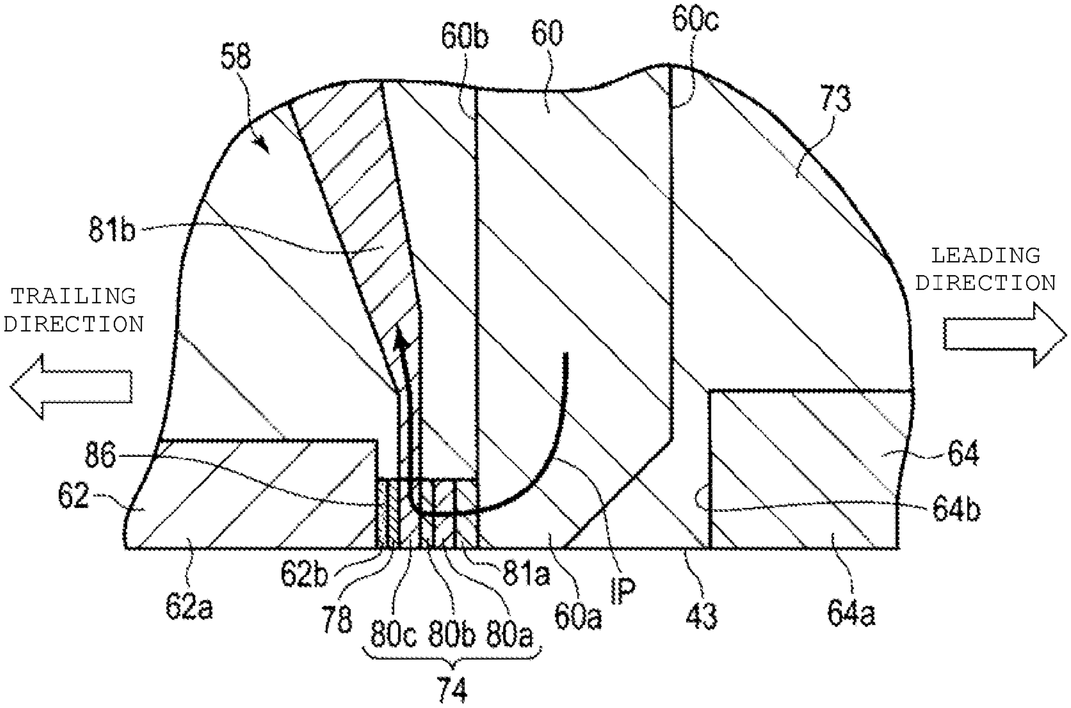
60c
73
81b
TRAILING
DIRECTION
LEADING
DIRECTION
78
62
64
64b
62b
81a
62a
80c 80b 80a
60a
IP
43
64a
74

FIG. 16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60b
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60c
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81b
TRAILING
DIRECTION
LEADING
DIRECTION
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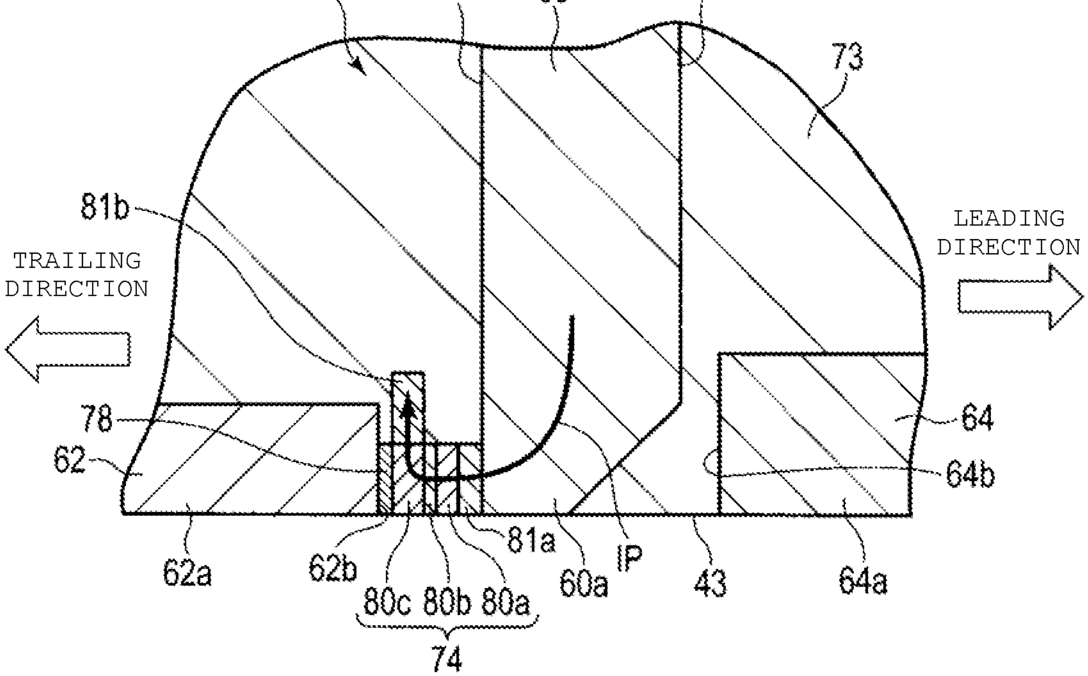
64b
62b
81a
IP
62a
78
80c
80b
80a
60a
43
64a
74

FIG. 17


58
60b
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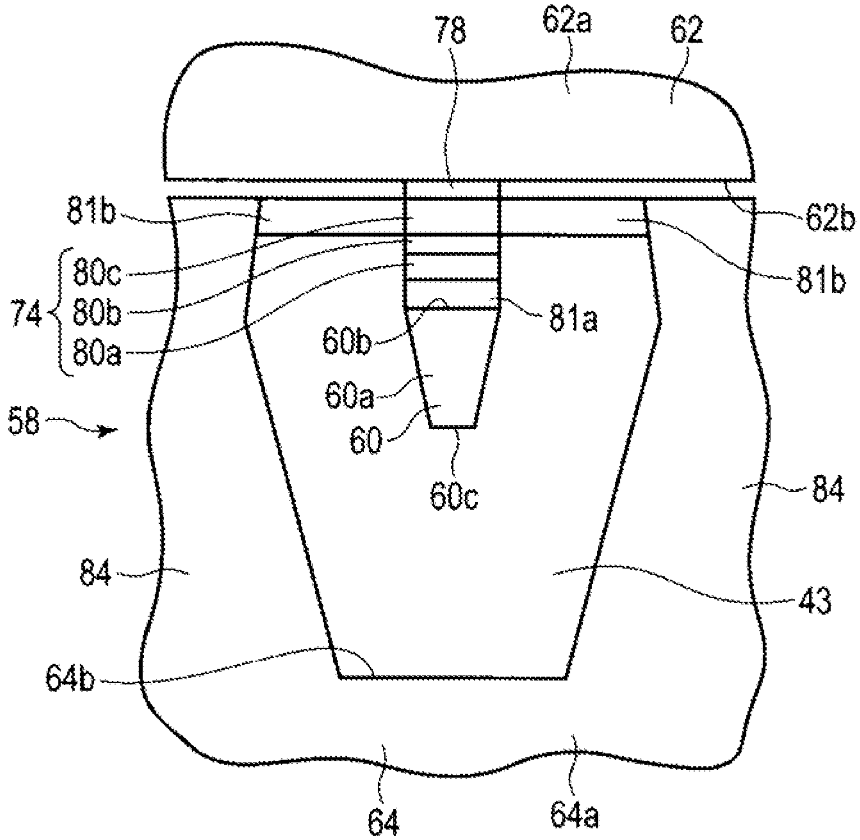
60c
73
81b
LEADING DIRECTION
TRAILING DIRECTION
78
62
64
64b
62a
62b
81a
60a
IP
43
64a
80c 80b 80a
74

FIG. 18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62a
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81b
62b
81b
80c
80b
80a
74
81a
60b
60a
60
60c
58
84
84
43
64b
64
64a

FIG. 19

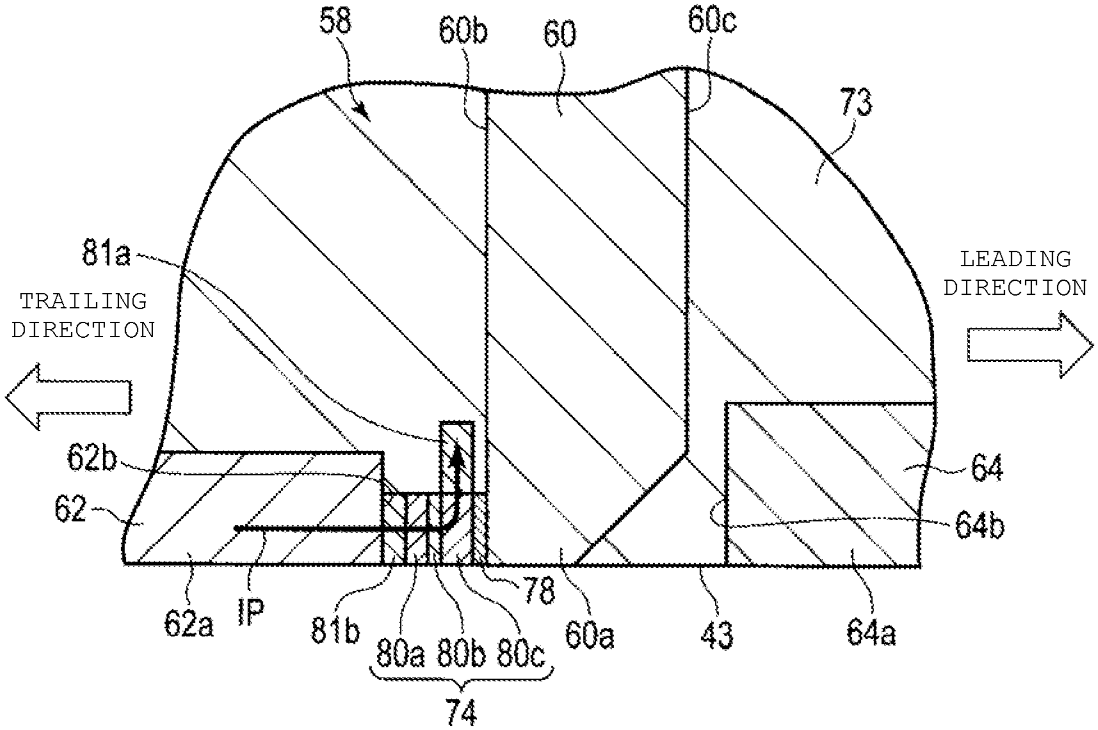
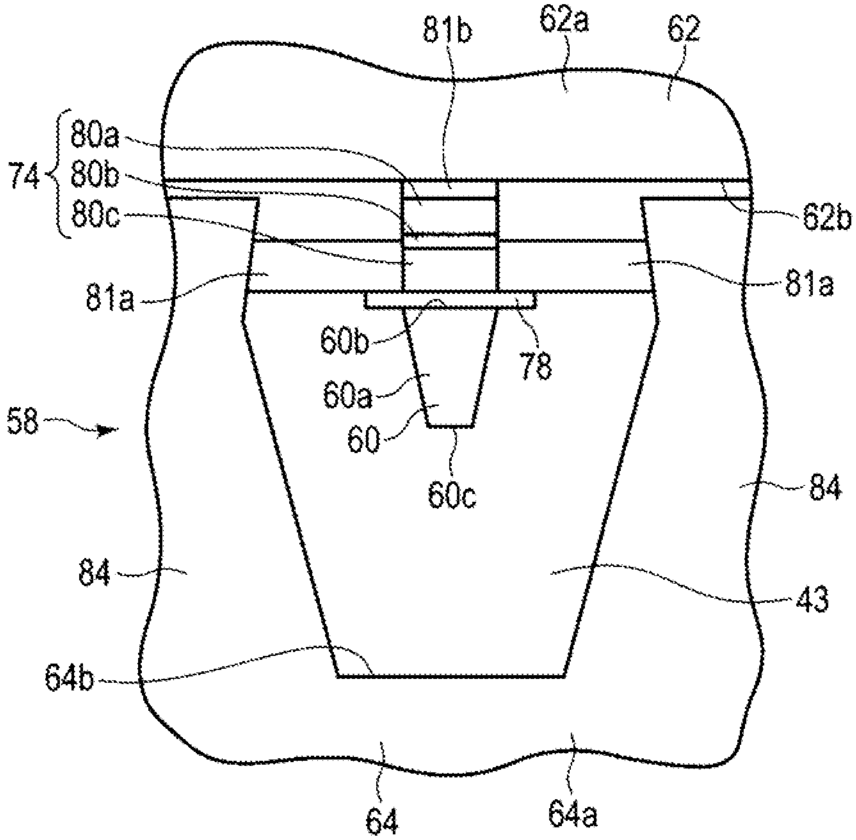

58
60b
60
60c
73
81a
TRAILING DIRECTION
LEADING DIRECTION
62b
62
64
64b
62a
IP
81b
80a
80b
80c
78
60a
43
64a
74

FIG. 20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80a
74
80b
80c
62b
81a
81a
60b
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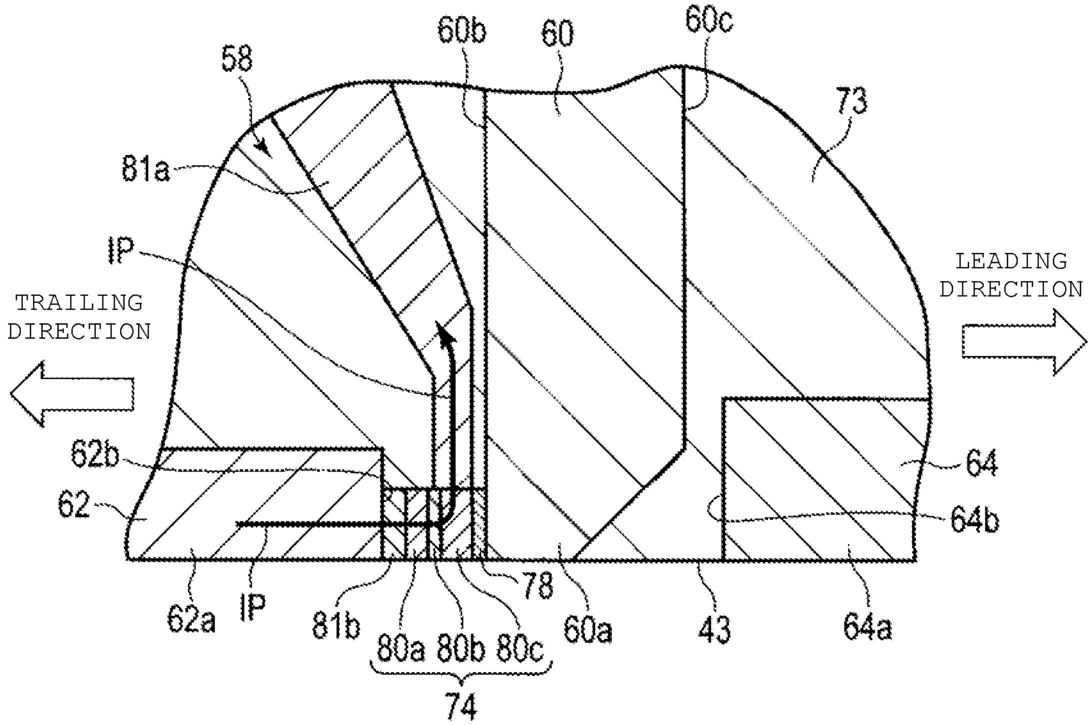
60a
58
60
60c
84
84
43
64b
64
64a

FIG. 21



58
60b
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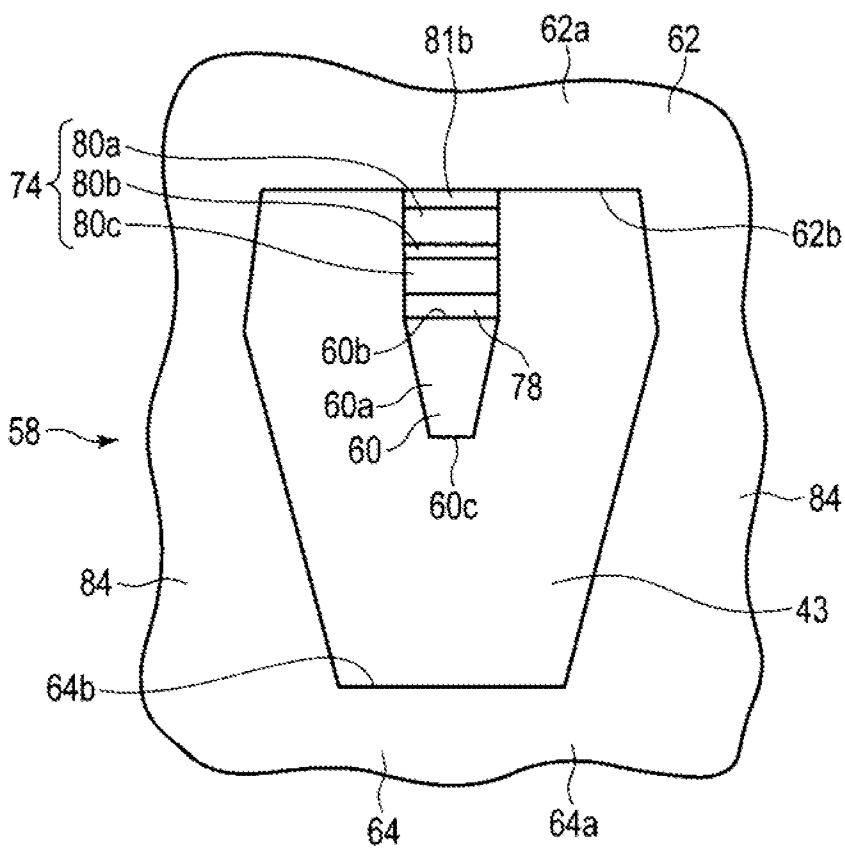
60c
73
81a
IP
TRAILING DIRECTION
LEADING DIRECTION
62b
62
64
64b
62a
IP
81b
80a
80b
80c
78
60a
43
64a
74

FIG. 22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62
74
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80b
80c
62b
60b
78
60a
58
60
60c
84
84
43
64b
64
64a

HIGH-FREQUENCY OSCILLATION DEVICE, MAGNETIC RECORDING HEAD INCLUDING THE SAME, AND DISK DEVICE

CROSS-REFERENCE TO RELATED APPLICATION

This application is based upon and claims the benefit of priority from Japanese Patent Application No. 2014-091409, filed Apr. 25, 2014, the entire contents of which are incorporated herein by reference.

BACKGROUND

Magnetic disk drives often include a magnetic head for perpendicular magnetic recording in order to provide for high recording density, large capacity, and miniaturization. In such a magnetic head, a recording head includes a main magnetic pole which generates a perpendicular magnetic field, a write shield which faces the main magnetic pole with a write gap therebetween, and a coil that causes a magnetic flux to flow through the main magnetic pole. In addition, a magnetic recording head for high-frequency assisted recording has been proposed, in which a high-frequency oscillator is disposed between a main magnetic pole and a write shield (i.e., within a write gap).

However, in the manufacture of a recording head and recording medium, it is difficult to produce a recording head for high-frequency assisted recording under optimal conditions. This is due in part to variations in a magnetic pole shape and a resonance property of the recording medium.

DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective view depicting a hard disk drive (HDD) according to a first embodiment.

FIG. **2** is a side view showing a floating magnetic head of the HDD.

FIG. **3** is an enlarged cross-sectional view depicting a head unit of the magnetic head.

FIG. **4** is an enlarged cross-sectional view depicting a tip portion of a recording head.

FIG. **5** is a plan view of the tip portion of the recording head when viewed from a disk facing surface side thereof.

FIG. **6** is a cross-sectional view depicting a field generation layer, a modulation insulating layer, and a modulation electrode.

FIG. **7** is a cross-sectional view of a field generation layer, a modulation insulating layer, and a modulation electrode according to a modification example.

FIG. **8** is a diagram depicting a relationship between a modulation voltage and an oscillating frequency of a spin torque oscillator (STO).

FIG. **9** is a diagram depicting a relationship between an oscillating frequency of an STO and an overwriting characteristic (OW).

FIG. **10** is a diagram depicting a relationship between the number of protrusions on one side surface of a field generation layer and an overwriting characteristic (OW).

FIG. **11** is a diagram depicting a relationship between a protrusion height/element size and an overwriting characteristic (OW).

FIG. **12** is a plan view of a recording head tip portion of a magnetic head in an HDD, as viewed from a disk facing surface side thereof, according to a second embodiment.

FIG. **13** is an enlarged cross-sectional view of a recording head tip portion of a magnetic head in an HDD according to a third embodiment.

FIG. **14** is a plan view of the recording head tip portion of the magnetic head in the HDD, as viewed from a disk facing surface side thereof, according to the third embodiment.

FIG. **15** is an enlarged cross-sectional view of a recording head tip portion of a magnetic head in an HDD according to a fourth embodiment.

FIG. **16** is an enlarged cross-sectional view of a recording head tip portion of a magnetic head in an HDD according to a fifth embodiment.

FIG. **17** is an enlarged cross-sectional view of a recording head tip portion of a magnetic head in an HDD according to a sixth embodiment.

FIG. **18** is a plan view of the recording head tip portion of the magnetic head in the HDD, as viewed from a disk facing surface side thereof, according to the sixth embodiment.

FIG. **19** is an enlarged cross-sectional view of a recording head tip portion of a magnetic head in an HDD according to a seventh embodiment.

FIG. **20** is a plan view of the recording head tip portion of the magnetic head in the HDD, as viewed from a disk facing surface side thereof, according to the seventh embodiment.

FIG. **21** is an enlarged cross-sectional view of a recording head tip portion of a magnetic head in an HDD according to an eighth embodiment.

FIG. **22** is a plan view of the recording head tip portion of the magnetic head in the HDD, as viewed from a disk facing surface side thereof, according to the eighth embodiment.

DETAILED DESCRIPTION

Embodiments provided herein provide a magnetic recording head capable of improving matching with a resonance property of a recording medium (thereby increasing the recording density), and a disk drive that includes the magnetic recording head.

According to an embodiment, a magnetic head of a disk drive includes a main magnetic pole that applies a recording magnetic field to a recording layer of a recording medium, a write shield that faces the main magnetic pole with a write gap therebetween, a recording coil that generates a magnetic field in the main magnetic pole, a high-frequency oscillator that is disposed within the write gap between the main magnetic pole and the write shield, a wiring electrically connected to the high-frequency oscillator through the main magnetic pole and the write shield, and a low pass filter that is electrically connected to the wiring.

Hereinafter, various embodiments will be described with reference to the accompanying drawings.

First Embodiment

FIG. **1** illustrates an internal structure of an HDD from which a top cover has been removed, according to a first embodiment. FIG. **2** illustrates a floating magnetic head. As illustrated in FIG. **1**, the HDD includes a housing **10**. The housing **10** includes a rectangular box-shaped base **10*a***, the top surface of which is exposed, and a rectangular plate-shaped top cover (not illustrated in the drawing). The top cover is threadably mounted on the base using a plurality of screws to close an upper end opening of the base. Thus, the inside of the housing **10** is held in an airtight manner, and is capable of communicating with the outside only through an aeration filter **26**.

A magnetic disk **12** that is a recording medium and a mechanism unit are provided on the base **10***a*. The mechanism unit includes a spindle motor **13** that supports and rotates the magnetic disk **12**, a plurality of, for example, two magnetic heads **33** that perform recording and reproducing of information on the magnetic disk, a head actuator **14** that movably supports the magnetic heads **33** with respect to the surface of the magnetic disk **12**, and a voice coil motor (VCM) **16** that rotates and positions the head actuator. Also provided on the base **10***a* are a ramp load mechanism **18** that holds the magnetic heads **33** at positions separated from the magnetic disk **12** when the magnetic heads **33** move to an outermost periphery of the magnetic disk **12**, a latching mechanism **20** that holds the head actuator **14** at a retraction position when an impact or the like is applied to the HDD, and a substrate unit **17** having electronic components such as a conversion connector mounted thereon.

A control circuit board **25** is threadably mounted on an outer surface of the base **10***a* and is located to face the bottom wall of the base **10***a*. The control circuit board **25** includes a power supply, a recording current circuit that supplies a recording current to the magnetic heads, a driving current circuit that supplies a driving current to a high-frequency oscillator, a modulation voltage circuit, and the like. The control circuit board **25** controls operations of the spindle motor **13**, the VCM **16**, and the magnetic head **33** through the substrate unit **17**.

As illustrated in FIG. **1**, the magnetic disk **12** is coaxially fitted to a hub of the spindle motor **13**, is clamped by a clamp spring **15** which is threadably mounted on an upper end of the hub, and is fixed to the hub. The magnetic disk **12** is rotated by the spindle motor **13** as a driving motor in the direction of an arrow B at a predetermined speed.

The head actuator **14** includes a bearing portion **21** which is fixed onto the bottom wall of the base **10***a*, a plurality of arms **27** extending from the bearing portion **21**, and elongated plate-shape suspensions **30** capable of being elastically deformed. Each suspension **30** is configured with a flat spring, and has a base end which is fixed to a tip of the arm **27** by spot welding or bonding, and which extends from the arm **27**. Each of the suspensions **30** may be integrally formed with the corresponding arm **27**. The magnetic head **33** is supported by an extended end of each suspension **30**.

As illustrated in FIG. **2**, each magnetic head **33** includes a slider **42** having a substantially rectangular parallelepiped shape and a head unit **44** for recording and reproducing, and which is provided in an outflow end (i.e., a trailing end) of the slider. The magnetic head **33** is fixed to a gimbal spring **41** provided at a tip portion of the suspension **30**. Ahead load L directed to the surface of the magnetic disk **12** is applied to each magnetic head **33** by the elasticity of the suspension **30**. The two arms **27** depicted in FIG. **1** are located parallel to each other with a predetermined gap therebetween, and the suspensions **30** and the magnetic heads **33**, which are attached to the respective arms **27**, face each other with the magnetic disk **12** interposed therebetween.

Each magnetic head **33** is electrically connected to a main flexible printed circuit (FPC) **38** (described later) through a relay flexible printed circuit board (relay FPC) **35** fixed onto the suspension **30** and the arm **27**.

As illustrated in FIG. **1**, the circuit board unit **17** includes an FPC main body **36** formed of a flexible printed circuit board, and the main FPC **38** that extends from the FPC main body. The FPC main body **36** is fixed onto the bottom surface of the base **10***a*. Electronic components including a conversion connector **37** and a head IC are mounted on the FPC main body **36**. An extended end of the main FPC **38** is connected to the head actuator **14** and is connected to the magnetic head **33** through each relay FPC **35**.

The VCM **16** includes a supporting frame (not illustrated), which extends in an opposite direction to the arm **27** from the bearing portion **21**, and a voice coil supported by the supporting frame. In a state where the head actuator **14** is embedded in the base **10***a*, the voice coil is located between a pair of yokes **34** fixed onto the base **10***a*, and configures the VCM **16** with the yokes **34** and magnets fixed to the yokes **34**.

The head actuator **14** is rotated by electrifying the voice coil of the VCM **16** while the magnetic disk **12** is rotated, and the magnetic heads **33** are moved onto and positioned on a desired track of the magnetic disk **12**. At this time, the magnetic heads **33** are moved between an inner peripheral edge and an outer peripheral edge of the magnetic disk along a radial direction of the magnetic disk **12**.

Next, configurations of the magnetic disk **12** and the magnetic head **33** will be described in detail. FIG. **3** is an enlarged cross-sectional view of the head unit **44** of the magnetic head **33** and the magnetic disk **12**.

As illustrated in FIGS. **2** and **3**, the magnetic disk **12** includes a substrate **101** which is formed of a non-magnetic material and which has a disk shape with a diameter of, according to embodiments, approximately 2.5 inches (6.35 cm). A soft magnetic layer **102**, which serves as a base layer, and which is formed of a material having a soft magnetic characteristic, a magnetic recording layer **103**, located on the soft magnetic layer **102**, and which has magnetic anisotropy in a direction perpendicular to a disk surface, and a protection film layer **104** located on the magnetic recording layer are laminated in order on the surface of the substrate **101**.

As illustrated in FIGS. **2** and **3**, the magnetic head **33**, configured as a floating type head, includes the slider **42** formed to have a substantially rectangular parallelepiped shape, and the head unit **44** is formed in an end on the outflow end (i.e., trailing) side of the slider. The slider **42** is formed, in embodiments, of a sintered body (AlTiC) of alumina and titanium carbide, and the head unit **44** is formed by laminating thin films.

The slider **42** has a rectangular disk facing surface (air bearing surface (ABS)) **43** facing the surface of the magnetic disk **12**. The slider **42** floats by an air flow C generated between the disk surface and the disk facing surface **43** by the rotation of the magnetic disk **12**. The direction of the air flow C conforms with a rotation direction B of the magnetic disk **12**. The slider **42** is disposed so that the longitudinal direction of the disk facing surface **43** substantially conforms to the direction of the air flow C, with respect to the surface of the magnetic disk **12**.

The slider **42** includes a leading end **42***a* located on an inflow side of the air flow C and a trailing end **42***b* located on an outflow side of the air flow C. A roughness structure (i.e., a leading step, side step, negative-pressure cavity, or the like), which is not illustrated in the drawing, is formed in the disk facing surface **43** of the slider **42**.

As illustrated in FIG. **3**, the head unit **44** includes a reproducing head **54** formed in the slider **42** through a thin-film process, and a recording head (magnetic recording head) **58**. The head unit is formed as a separation-type magnetic head. The reproducing head **54** and the recording head **58** (other than portions thereof exposed by the ABS **43** of slider **42**) are covered by a non-magnetic protection insulating film **73** which, in embodiments, is formed of alumina or silicon oxide. The protection insulating film. **73** forms a contour of the head unit **44**.

The reproducing head **54** includes a magnetic film. **55** that exhibits a magnetoresistance effect, and shield films **56** and **57**, which are disposed on the trailing side and the leading side of the magnetic film **55** with the magnetic film **55** interposed therebetween. Lower ends of the magnetic film **55** and the shield films **56** and **57** are exposed by the disk facing surface **43** of the slider **42**.

The recording head **58** is provided on the trailing end **42***b* side of the slider **42** with respect to the reproducing head **54**. The recording head **58** includes a main magnetic pole **60**, which is formed of a highly permeable material, and which generates a recording magnetic field in a direction perpendicular to the surface of the magnetic disk **12**. The recording head also includes a trailing shield (write shield) **62** and a leading shield **64**. The recording head **58** configures a first magnetic core for forming a magnetic path, which is configured with the main magnetic pole **60** and the trailing shield **62**, and a second magnetic core for forming a magnetic path which is configured with the main magnetic pole **60** and the leading shield **64**. The recording head **58** includes a first recording coil **70**, which is wound around the first magnetic core to cause a magnetic flux to flow through the main magnetic pole **60** when writing a signal on the magnetic disk **12**, a second recording coil **72**, which is wound around the second magnetic core, and a high-frequency oscillator, such as spin torque oscillator (STO) **74**, which is provided in a portion facing the ABS **43** between a tip portion **60***a* of the main magnetic pole **60** and a tip portion **62***a* of the trailing shield **62**. In this embodiment, the recording head **58** includes a modulation electrode **76**, which applies a modulation voltage to the STO **74**, and a modulation insulating layer **78**, which is interposed between the modulation electrode **76** and the STO.

In this way, the spin torque oscillator **74**, the modulation electrode **76**, and the modulation insulating layer **78** configure a high-frequency oscillation device.

The first recording coil **70** and the second recording coil **72** are electrically connected to a recording current circuit **200** of the control circuit board **25** shown in FIG. **1** through first wirings L**1** and L**2** provided within the slider **42** and through the relay FPC **35** and the circuit board unit **17**. The main magnetic pole **60** and the trailing shield **62** are electrically connected to an STO driving current circuit **202** of the control circuit board **25** through second wirings L**3** and L**4** provided within the slider **42** and through the relay FPC **35** and the circuit board unit **17**. Further, the modulation electrode **76** is electrically connected to a modulation voltage circuit **204** of the control circuit board **25** through a third wiring L**5** provided within the slider **42** and through the relay FPC **35** and the circuit board unit **17**.

FIG. **4** is an enlarged cross-sectional view of an end of the recording head **58** on the ABS **43** side and the STO **74**, FIG. **5** is a plan view of a tip portion of the recording head on the ABS side when viewed from the ABS side, and FIG. **6** is a cross-sectional view of a field generation layer (FGL) of the STO and the modulation insulating layer **78**.

As illustrated in FIGS. **3** to **5**, the main magnetic pole **60** extends in a direction substantially perpendicular to the surface of the magnetic disk **12** and the ABS **43**. The tip portion **60***a* of the main magnetic pole **60** on the magnetic disk **12** side is narrowed in a tapering manner toward the ABS **43**. The tip portion **60***a* of the main magnetic pole **60** includes a trailing side end face **60***b*, having a predetermined width (i.e., a track width), which is located on the trailing end side, and a leading side end face **60***c* that faces the trailing side end face. A tip face of the main magnetic pole **60** is exposed by the ABS **43** of the slider **42**.

The trailing shield **62** (shown in FIG. **3**) is formed of a soft magnetic material having a high saturation magnetic flux density, is disposed on the trailing side of the main magnetic pole **60**, and is provided to efficiently close a magnetic path through the soft magnetic layer **102** just below the main magnetic pole. The trailing shield **62** is formed to have a substantially L shape, and includes a first connection portion **50** at a position separated from the ABS **43**. The first connection portion **50** is connected to an upper portion of the main magnetic pole **60**, that is, the upper portion (or back gap) which is separated from the ABS **43** through a non-conductor **52**. In addition, the main magnetic pole **60** and the trailing shield are electrically insulated from each other by the non-conductor **52** at the position of the first connection portion **50**.

The tip portion **62***a* of the trailing shield **62** is formed to have an elongated rectangular shape and has a tip face which is exposed by the disk facing surface **43** of the slider **42**. A leading side end face **62***b* (as shown in FIG. **4**) of the tip portion **62***a* extends along a width direction (i.e., a cross-track direction) of the track of the magnetic disk **12**. The leading side end face **62***b* faces the trailing side end face **60***b* of the main magnetic pole **60** in parallel with a write gap WG (a gap length in a down-track direction) therebetween.

In embodiments, the first recording coil **70** is wound around the first connection portion **50** between the main magnetic pole **60** and the trailing shield **62**.

The leading shield **64** is formed of a soft magnetic material and faces the main magnetic pole **60** on the leading side of the main magnetic pole **60**. The leading shield **64** is formed to have a substantially L shape, and the tip portion **64***a* on the magnetic disk **12** side is formed to have an elongated rectangular shape. A tip face (i.e., a lower end face) of the tip portion **64***a* is exposed by the disk facing surface **43** of the slider **42**. A trailing side end face **64***b* of the tip portion **64***a* extends along the width direction of the track of the magnetic disk **12**. The trailing side end face **64***b* faces the leading side end face **60***c* of the main magnetic pole **60** in parallel with a gap therebetween. The protection insulating film **73** is a non-magnetic material and is located at the gap.

The leading shield **64** has a second connection portion at a position separated from the ABS **43**. The second connection portion **68** is connected to an upper portion of the main magnetic pole **60** (i.e., a back gap) which is separated from the ABS **43** through a non-conductor **69**. The second connection portion **68** is formed of, in embodiments, a soft magnetic material, and configures a magnetic circuit with the main magnetic pole **60** and the leading shield **64**. In addition, the main magnetic pole **60** and the leading shield **64** are electrically insulated from each other by the non-conductor **69** at the position of the second connection portion **68**.

As illustrated in the embodiment of FIG. **3**, the second recording coil **72** is wound around the second connection portion **68** between the main magnetic pole **60** and the leading shield **64**. The second recording coil **72** is wound in an opposite direction to the first recording coil **70**. In addition, the second recording coil **72** is connected to the first recording coil **70** in series. Meanwhile, the supply of a current to the first recording coil **70** and the second recording coil **72** may be controlled separately. When a signal is written on the magnetic disk **12**, a predetermined current is supplied to the first recording coil **70** and to the second recording coil **72** from the recording current circuit **200**, which causes a magnetic flux to flow through the main magnetic pole **60**, thereby generating a magnetic field.

In the recording head **58** described above, a soft magnetic material to be used for configuring the main magnetic pole **60**, the trailing shield **62**, and the leading shield **64**, may be selected from an alloy containing at least one of Fe, Co, and Ni, or a compound thereof.

As illustrated in FIGS. **4** and **5**, the STO **74** is provided within the write gap WG between the trailing side end face **60***b* of the main magnetic pole **60** and the leading side end face **62***b* of the trailing shield **62**. The STO **74** includes a spin injection layer (SIL) **80***a*, an intermediate layer **80***b*, and a field generation layer (FGL) **80***c*, which are laminated in this order from the main magnetic pole **60** toward the trailing shield **62**, and along a direction parallel to the ABS **43**. The SIL **80***a*, the intermediate layer **80***b*, and the FGL **80***c* extend substantially perpendicular to the ABS **43**. Lower end faces of the SIL **80***a*, the intermediate layer **80***b*, and the FGL **80***c* are exposed by the ABS **43** and are formed to be flat with the ABS **43**.

A first electrode layer **81***a* is provided between the main magnetic pole **60** and the SIL **80***a* of the STO **74** so that electrification is performed in the order of the main magnetic pole **60**, the STO **74**, and the trailing shield **62**. Further, a second electrode layer **81***b* is provided between the FGL **80***c* of the STO **74** and the trailing shield **62**. An electrification circuit for electrifying the STO **74** is configured with the main magnetic pole **60**, the STO **74**, and the trailing shield **62**.

As illustrated in FIG. **3**, the main magnetic pole **60** and the trailing shield **62** are connected to the STO driving current circuit (i.e., power supply) **202** through the second wirings L**3** and L**4**. It is possible that a driving current Ip of the STO **74** flows, in series, through the main magnetic pole **60** and the trailing shield **62** from the STO driving current circuit **202**.

A size (width and height) of each of the FGL **80***c* and the SIL **80***a* of the STO **74** is, in embodiments, 20×20 nm, and film thicknesses of the FGL and the SIL are 15 nm and 8 nm, respectively. The FGL **80***c* is formed of FeCoB, and the SIL **80***a* is configured with, in embodiments, a Co/Pt artificial lattice. The intermediate layers **80***b* and **82***b* are formed of Cu or the like. In addition, the FGL **80***c* and the SIL **80***a* may be configured with an alloy containing at least one of Fe, Co, and Ni, a Co/Ni artificial lattice, a Fe/Co artificial lattice, a Co/Pd artificial lattice, a FeCo/Ni artificial lattice, a Heusler alloy (such as CoFeMnGe or CoFeMnSi), or a laminated body thereof.

As illustrated in FIG. **6**, at least the field generation layer (FGL) **80***c* includes a main body **82***a* having a substantially rectangular shape and a protrusion structure having a plurality of protrusions **82***b* that protrude from the sides of the main body. The main body **82***a* has four sides, and the plurality of protrusions **82***b* protrude from at least one side of the main body **82***a*, with the exception of the side exposed by the ABS **43**. In this embodiment, the protrusion structure is formed in three sides in an element height direction (upper side) and a core width direction (lateral sides) of the main body **82***a*. The protrusion **82***b* is formed to have, for example, a substantially triangular shape, and has a protrusion height h from a lateral side of the main body **82***a*.

According to this embodiment, the SIL **80***a* and the intermediate layer **80***b* have the same protrusion structure as that of the FGL **80***c*, and are formed to have the same cross-sectional shape as that of the FGL **80***c*.

The protrusion structure may not be provided in all of three sides of the main body **82***a*, and may be provided in two facing lateral sides of the main body **82***a* or in only one lateral side, as illustrated in FIG. **7**.

As illustrated in FIGS. **4** to **6**, the modulation insulating layer **78** is formed to come into contact with at least the outer surface of the FGL **80***c*, and surrounds the FGL **80***c* from three directions (i.e., the element height direction and the core width directions). The modulation insulating layer **78** is formed to have a substantially fixed film thickness, and is formed to resemble the shape of the protrusion **82***b* of the FGL **80***c*. In this embodiment, the modulation insulating layer **78** is provided to cover lateral sides of the high-frequency oscillator **74** and the first and second electrode layers **81***a* and **81***b*.

The modulation insulating layer **78** is formed of an oxide containing MgO, and has a film thickness of 2 nm. In addition, an insulator containing oxygen such as AlOx, SiOx, or TiOx, and having high resistance, dielectric strength, and a large relative dielectric constant, may be used as the modulation insulating layer **78**.

The modulation electrode **76** surrounds the modulation insulating layer **78** from three directions (i.e., the element height direction and the core width directions), and is formed to resemble the shape of the protrusion of the modulation insulating layer **78**. The modulation electrode **76** covers at least the vicinity of the FGL **80***c* with the modulation insulating layer **78** interposed therebetween. That is, the modulation insulating layer **78** is interposed between the modulation electrode **76** and the FGL **80***c*.

As illustrated in FIG. **3**, the modulation electrode **76** is electrically connected to the modulation voltage circuit **204** through the third wiring L**5**, and the trailing shield **62** is electrically connected to the modulation voltage circuit **204** through the second wiring L**4**. A voltage is applied between the modulation electrode **76** and the trailing shield **62** from the modulation voltage circuit **204**. Thus, it is possible to apply a voltage to the FGL **80***c*, thereby modulating an oscillating frequency.

In the recording head **58** configured in the above-described manner, as illustrated in FIGS. **3** and **4**, the driving current Ip flows to the STO **74** through the second wirings L**3** and L**4**, the main magnetic pole **60**, and the trailing shield **62** from the STO driving current circuit **202**, while a recording current flows to the first and second recording coils **70** and **72** from the recording current circuit **200**, and thus the STO **74** oscillates. Regarding the STO driving current Ip, a direct current flows, and thus it is possible to oscillate the STO **74** with a fixed oscillating frequency, regardless of a recording signal (i.e., a recording current) being positive or negative. In the STO driving current Ip, components that change synchronously with the recording current may be superposed on direct current components. It is possible to stabilize an oscillating frequency of the STO **74** and to accelerate the return of a frequency by the switching of the recording signal due to the superposition. Accordingly, the transition of a recording bit becomes clear, and thus it is possible to perform high-frequency assisted recording in a higher density.

The modulation voltage circuit **204** applies a modulation voltage to the FGL **80***c* and the modulation insulating layer **78** through the trailing shield **62**. The oscillating frequency of the STO **74** can be shifted (modulated) by the application of a direct current to the modulation voltage, and thus it is possible to apply a high-frequency magnetic field, which is more suitable for a resonance frequency of the recording medium, to the recording medium from the STO **74**. As a result, a recording characteristic of the high-frequency assisted recording is improved, which allows for high-density recording. In the modulation voltage, components that change synchronously with the recording current may be superposed on direct current components. It is possible to stabilize an oscillating frequency of the STO and to accelerate the return of a frequency by the switching of the recording signal due to the superposition. As a result, the transition of a recording bit becomes clear, and thus it is possible to perform high-frequency assisted recording in a higher density.

FIG. **8** illustrates a relationship between a modulation voltage and an oscillating frequency. FIG. **9** illustrates a relationship between an overwriting characteristic (OW) and an oscillating frequency. The oscillating frequency of the STO **74** is measured in a state where a recording current of 40 mA is applied to the first and second recording coils **70** and **72**. With this recording current, the main magnetic pole **60** is almost saturated, and thus the oscillating frequency of the STO **74** does not change in spite of an increase in the recording current. In such a case, the oscillation frequency is a constant 18 GHz.

As illustrated in FIG. **8**, when a modulation voltage of −1,700 mV to +1,700 mV is applied, the oscillating frequency of the STO **74** changes between 20 GHz and 22.3 GHz. This indicates that an electric field is applied to the modulation insulating layer **78** by applying the modulation voltage. Charges proportional to the product of an electric field intensity and a relative dielectric constant of the modulation insulating layer **78** are induced to an interface between the modulation insulating layer **78** and the FGL **80***c*. As a result, surface magnetic anisotropy of the FGL **80***c* in the interface between the modulation insulating layer **78** and the FGL **80***c* changes. That is, density of state (DOS) in a Fermi surface changes by injecting charges, and magnetic anisotropy derived from Fe—O bonding changes. Further, the oscillating frequency of the STO **74** is proportional to a mean effective magnetic field in the entire FGL **80***c* (i.e., the sum of an external magnetic field, a self-demagnetizing field, and magnetic anisotropy). For this reason, as a result of the change in the surface magnetic anisotropy of the FGL **80***c*, a mean effective magnetic field changes in the entire FGL **80***c*, and the oscillating frequency of the STO **74** changes. Meanwhile, since the surface magnetic anisotropy of the FGL **80***c* being positive or negative changes according to the modulation voltage being positive or negative, the oscillating frequency change of the STO **74** is positive or negative.

In addition, as illustrated in FIG. **9**, a long-wavelength recording signal is overwritten on a short-wavelength recording signal, and an overwriting characteristic (OW) indicating the degree to which a short wavelength remains is measured. The OW characteristic changes by applying the modulation voltage, and it is possible to obtain an optimal OW characteristic when the oscillating frequency of the STO is approximately 20 GHz. Thus, it can be seen that high-frequency assisted recording can be performed in a higher density. This is because matching with the resonance frequency of the recording medium is improved.

According to this embodiment, the modulation insulating layer **78** is formed to surround the FGL **80***c* from three directions (i.e., the element height direction and the core width directions). It is possible to increase the area of the interface between the FGL **80***c* and the modulation insulating layer **78** by surrounding the FGL **80***c* from three directions. The change in the mean effective magnetic field in the entire FGL **80***c* is proportional to the area of the interface between the FGL **80***c* and the modulation insulating layer **78**. For this reason, the interface between the FGL **80***c* and the modulation insulating layer **78** is formed in surfaces in two or more directions, and thus it is possible to increase the contribution of surface magnetic anisotropy to the mean effective magnetic field. As a result, it is possible to perform oscillating frequency control (i.e., modulation control) in a wide range. Even in a magnetic head having a great variation at the time of manufacture, oscillation can be performed with an oscillating frequency which is most suitable for high-frequency assisted recording by controlling a modulation voltage, and thus it is possible to perform high-frequency assisted recording in a higher density.

FIG. **10** illustrates a relationship between the number of protrusions in one lateral side of the main body **82***a* of the FGL **80***c* and an overwriting characteristic OW. When the FGL **80***c* does not include a protrusion structure, that is, when the number of protrusions is zero, the overwriting characteristic is −17 dB. The number of protrusions is set to equal to or greater than one and less than five, and thus the overwriting characteristic is improved to equal to or less than −18 dB. On the other hand, when the number of protrusions is set to equal to or greater than five, the overwriting characteristic is set to −17 dB. For this reason, it is preferable that the number of protrusions formed in one lateral side be set to equal to or greater than one and less than five. This indicates that the surface area of the FGL **80***c* is increased by giving the protrusion structure to the FGL **80***c*, which allows a great change in surface magnetic anisotropy to be obtained.

On the other hand, when the number of protrusions increases, the individual protrusions become smaller, and thus an exchange coupling force between each protrusion **82***b* and the main body **82***a* is decreased. This is due to the fact that it becomes difficult to transmit the change in surface magnetic anisotropy induced in the protrusion structure to the main body **82***a*.

FIG. **11** illustrates a relationship between an overwriting characteristic OW and a ratio (protrusion height/element size) of a height h of the protrusion **82***b* to an element size (i.e., a size of the main body **82***a*). When the protrusion height/element size is zero, that is, when the FGL **80***c* does not include a protrusion structure, the overwriting characteristic is −17 dB. As the height h of the protrusion increases, the overwriting characteristic is improved. In addition, if the protrusion height/element size is set to equal to or greater than 0.3 and equal to or less than 1, then the overwriting characteristic is improved to equal to or less than −18 dB.

On the other hand, when the protrusion height/element size is set equal to or greater than 1.5, the overwriting characteristic is set to −17 dB. For this reason, it is preferable that the protrusion height/element size be set to equal to or greater than 0.3 and equal to or less than 1. This indicates that the surface area of the FGL **80***c* is increased by increasing the height h of the protrusion, which allows a great change in surface magnetic anisotropy to be obtained. On the other hand, when the height h of the protrusion increases, a distance between the tip of the protrusion structure and the main body **82***a* increases, and an exchange coupling force between the protrusion structure and the main body is decreased. This is due to the fact that it becomes difficult to transmit the change in surface magnetic anisotropy induced in the protrusion structure to the main body.

In the above-described measurement, the modulation voltage is applied in a range between −1,700 mV and +1,700 mV. This is because the application of a modulation voltage equal to or higher than this range results in dielectric breakdown of the modulation insulating layer **78**. For this reason, it is preferable that the modulation insulating layer **78** have a great dielectric strength. It is possible to apply a high modulation voltage by using the modulation insulating layer **78** having a great dielectric strength, and thus it is possible to perform oscillating frequency control in a wide range. Even in a magnetic head having a great variation at the time of manufacture, oscillation can be performed with an oscillating frequency which is most suitable for high-frequency assisted recording by adjusting a modulation voltage, and thus it is possible to perform high-frequency assisted recording in a higher density.

It is preferable that the modulation insulating layer **78** have a large relative dielectric constant. The using of the modulation insulating layer **78** having a large relative dielectric constant allows more charges to be induced to the interface between the modulation insulating layer **78** and the FGL **80***c* even when the same modulation voltage is applied, which results in a great increase in the change of the surface magnetic anisotropy of the FGL **80***c*. As a result, it is possible to perform oscillating frequency control of the STO **74** in a wide range. For this reason, even in a magnetic head having a great variation, oscillation can be performed with an oscillating frequency which is most suitable for high-frequency assisted recording. Thus, it is possible to perform high-frequency assisted recording in a higher density.

According to the HDD configured in the above-described manner, the head actuator **14** is rotated by driving the VCM **16**, and the magnetic heads **33** move onto and are positioned on a desired track of the magnetic disk **12**. In addition, the magnetic heads **33** float by an air flow C (shown in FIG. **2**) generated between the disk surface and the ABS **43** due to the rotation of the magnetic disk **12**. During the operation of the HDD, the ABS **43** of the slider **42** faces the disk surface with a gap therebetween. As illustrated in FIG. **2**, the magnetic head **33** floats while taking an inclined posture in which the portion of the recording head **58** of the head unit **44** is closest to the surface of the magnetic disk **12**. In this state, the reading and writing of recording information from and on the magnetic disk **12** are performed using the reproducing head **54** and the recording head **58**, respectively.

In the writing of the information, as illustrated in FIG. **3**, a direct current flows to the STO **74** from the STO driving current circuit **202** to generate a high-frequency magnetic field from the STO **74**. The high-frequency magnetic field is applied to the magnetic recording layer **103** of the magnetic disk **12**. In addition, a recording current flows to the first and second recording coils **70** and **72** from the recording current circuit **200**, the main magnetic pole **60** is excited by the first and second recording coils **70** and **72**, and a perpendicular recording magnetic field is applied to the recording layer **103** of the magnetic disk **12**, which is located just below the main magnetic pole **60**. Thus, information is recorded on the magnetic recording layer **103** in a desired track width. The high-frequency magnetic field is superposed on the recording magnetic field, and thus it is possible to perform magnetic recording with a high degree of retention and high magnetic anisotropy energy. Further, during the writing of information, a modulation voltage is applied to the FGL **80***c* of the STO **74** through the modulation electrode **76** and the trailing shield **62** from the modulation voltage circuit **204**, and an oscillating frequency of the STO **74** is modulated and controlled to a frequency suitable for a resonance frequency of the magnetic disk **12**. Accordingly, oscillation can be performed with an oscillating frequency that is most suitable for high-frequency assisted recording, and thus it is possible to achieve high-frequency assisted recording in a higher density.

According to the first embodiment configured in the above-described manner, it is possible to obtain a high-frequency oscillation device capable of improving matching with a resonance property of a recording medium (thereby increasing the recording density), a magnetic recording head, and a disk drive including the magnetic recording head.

Next, a magnetic recording head of an HDD according to another embodiment will be described. In the other embodiment (described below), the same components as those in the first embodiment described above are denoted by the same reference numerals, and the detailed description thereof will be omitted. A detailed description is made with a focus on components different from those in the first embodiment.

Second Embodiment

FIG. **12** is a plan view of a tip portion of a magnetic recording head in an HDD (as viewed from an ABS) according to a second embodiment.

According to the second embodiment, as illustrated in FIG. **12**, a recording head **58** further includes a pair of side shields **84**. The pair of side shields **84** is formed of a soft magnetic material integrally with a trailing shield **62** and a leading shield **64**. The side shields **84** are physically distributed to both sides of a main magnetic pole **60** in a track width direction from the main magnetic pole **60**, and are magnetically and electrically connected to the trailing shield **62** and the leading shield **64**. Tip faces of the side shields **84** are exposed by an ABS **43**.

In this manner, providing the side shields **84** reduces the leakage of a magnetic field in the track width direction from the main magnetic pole **60**, making it possible to further increase recording density in the track width direction. Accordingly, it is possible to perform high-frequency assisted recording in a higher density.

Third Embodiment

FIG. **13** is a cross-sectional view showing a tip portion of a magnetic recording head in an HDD according to a third embodiment. FIG. **14** is a plan view of the tip portion of the magnetic recording head when viewed from an ABS.

As illustrated in FIGS. **13** and **14**, according to the third embodiment, a recording head **58** includes a pair of side shields **84**. The pair of side shields **84** are formed of a soft magnetic material integrally with a leading shield **64**, and extend to a trailing shield **62** side from the leading shield. The side shields **84** are physically distributed to both sides of a main magnetic pole **60** in a track width direction from the main magnetic pole **60**, and are magnetically and electrically connected to the leading shield **64**.

A modulation electrode **76** is provided so as to surround three sides of an STO **74**, and is electrically connected to the side shield **84**. As a result, it is possible to apply an electric field to a modulation insulating layer **78** through an FGL **80***c* of the STO **74** and the modulation electrode **76**. In addition, the leakage of a magnetic field in the track width direction from the main magnetic pole **60** is reduced, and it is therefore possible to further increase recording density in the track width direction. Accordingly, it is possible to perform high-frequency assisted recording in a higher density.

In addition, it is possible to change an application path of a modulation voltage as follows.

Fourth Embodiment

FIG. **15** is a cross-sectional view showing a tip portion of a magnetic recording head in an HDD according to a fourth embodiment. According to this embodiment, a modulation insulating layer **78** is provided between a leading side end face **62***b* of a trailing shield **62** and an FGL **80***c* of a STO **74**. In addition, an electrode layer **81***b* of the STO **74** surrounds three sides of the FGL **80***c* of the STO **74** and is electrically connected to an STO driving current circuit **202** through a second wiring. Thus, a driving current Ip flows through a main magnetic pole **60**, the STO **74**, and the electrode layer

81*b* from the STO driving current circuit **202**. In addition, it is possible to apply an electric field to the modulation insulating layer **78** through the trailing shield **62** from a modulation voltage circuit **204**. Further, in this embodiment, a protrusion structure of the FGL **80***c* is provided in a surface facing the modulation insulating layer **78** (i.e., a surface perpendicular to an ABS **43**).

Fifth Embodiment

FIG. **16** is a cross-sectional view showing a tip portion of a magnetic recording head in an HDD according to a fifth embodiment. According to this embodiment, a modulation insulating layer **78** is provided between a leading side end face **62***b* of a trailing shield **62** and an FGL **80***c* of an STO **74**, and a film thickness adjustment electrode **86** formed of a non-magnetic metal is provided between the modulation insulating layer **78** and the leading side end face **62***b* of the trailing shield **62**. It is possible to adjust a film thickness of the modulation insulating layer **78** to an optimal value using the film thickness adjustment electrode **86**. In the fifth embodiment, other components are the same as in the fourth embodiment.

Sixth Embodiment

FIG. **17** is a cross-sectional view showing a tip portion of a magnetic recording head in an HDD according to a sixth embodiment. FIG. **18** is a plan view of the tip portion of the magnetic recording head when viewed from an ABS.

As illustrated in FIGS. **17** and **18**, according to the sixth embodiment, a recording head **58** includes a pair of side shields **84**. The pair of side shields **84** are formed of a soft magnetic material integrally with a leading shield **64**, and extend to a trailing shield **62** side from the leading shield. The side shields **84** are physically distributed to both sides of a main magnetic pole **60** in a track width direction from the main magnetic pole **60**, and are magnetically and electrically connected to the leading shield **64**. The leading shield **64** is electrically connected to an STO driving current circuit through a second wiring.

As shown in FIG. **17**, a modulation insulating layer **78** is provided between a leading side end face **62***b* of the trailing shield **62** and an FGL **80***c* of an STO **74**. In addition, an electrode layer **81***b* of the STO surrounds three sides of the FGL **80***c* of the STO **74** and is electrically connected to the side shield **84**. Thus, a driving current Ip flows through the main magnetic pole **60**, the STO **74**, the electrode layer **81***b*, the side shields **84**, and the leading shield **64** from an STO driving current circuit **202**. In addition, it is possible to apply an electric field to the modulation insulating layer **78** through the trailing shield **62** from a modulation voltage circuit **204**. Further, in this embodiment, a protrusion structure of the FGL **80***c* is provided in a surface facing the modulation insulating layer **78** (i.e., a surface perpendicular to an ABS **43**).

Seventh Embodiment

FIG. **19** is a cross-sectional view showing a tip portion of a magnetic recording head in an HDD according to a seventh embodiment. FIG. **20** is a plan view of the tip portion of the magnetic recording head when viewed from an ABS.

As illustrated in FIGS. **19** and **20**, according to the seventh embodiment, a recording head **58** includes a pair of side shields **84**. The pair of side shields **84** are formed of a soft magnetic material integrally with a leading shield **64**, and extend to a trailing shield **62** side from the leading shield. The side shields **84** are physically distributed to both sides of a main magnetic pole **60** in a track width direction from the main magnetic pole **60**, and are magnetically and electrically connected to the leading shield **64**. The leading shield **64** is electrically connected to an STO driving current circuit through a second wiring. In addition, the main magnetic pole **60** is electrically connected to a modulation voltage circuit **204** through a third wiring.

A spin injection layer (SIL) **80***a*, an intermediate layer **80***b*, and a field generation layer (FGL) **80***c* of an STO **74** are laminated (in order) toward the main magnetic pole **60** from the trailing shield **62** side. The SIL **80***a* is electrically connected to a leading side end face **62***b* of the trailing shield **62** through an electrode layer **81***b*.

A modulation insulating layer **78** is provided between a trailing side end face **60***b* of the main magnetic pole **60** and the FGL **80***c* of the STO **74**. In addition, an electrode layer **81***a* of the STO surrounds three sides of the FGL **80***c* of the STO **74** and is electrically connected to the side shields **84**. Thus, a driving current Ip of the STO **74** flows through the trailing shield **62**, the STO **74**, the electrode layer **81***a*, the side shields **84**, and the leading shield **64** from an STO driving current circuit **202**. In addition, it is possible to appropriately apply an electric field to the modulation insulating layer **78** through the main magnetic pole **60** from the modulation voltage circuit **204**. Further, in this embodiment, a protrusion structure of the FGL **80***c* is provided in a surface facing the modulation insulating layer **78** (i.e., a surface perpendicular to an ABS **43**).

Eighth Embodiment

FIG. **21** is a cross-sectional view showing a tip portion of a magnetic recording head in an HDD according to an eighth embodiment. FIG. **22** is a plan view of the tip portion of the magnetic recording head when viewed from an ABS.

As illustrated in FIGS. **21** and **22**, an electrode layer **81***a* of an STO is separated from side shields **84** and may be configured as an independent electrode. In this case, the electrode layer **81***a* is electrically connected to an STO driving current circuit **202** directly through a second wiring. In the eighth embodiment, other components are the same as those in the seventh embodiment.

According to the second to eighth embodiments described above, it is possible to obtain the same operational effects as those in the first embodiment. That is, according to the second to eighth embodiments, it is possible to obtain a high-frequency oscillation device capable of improving matching with a resonance property of a recording medium (thereby increasing the recording density), a magnetic recording head, and a disk drive including the magnetic recording head.

While certain embodiments have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the inventions. Indeed, the novel embodiments described herein may be embodied in a variety of other forms; furthermore, various omissions, substitutions and changes in the form of the embodiments described herein may be made without departing from the spirit of the inventions. The accompanying claims and their equivalents are intended to cover such forms or modifications as would fall within the scope and spirit of the inventions.

For example, the materials, shapes and sizes of structural elements of a head unit can be changed if necessary. In a magnetic disk drive, the number of magnetic disks and magnetic heads can be increased if necessary, and the size of the magnetic disk can be variously selected.

What is claimed is:

1. A spin torque type high-frequency oscillation device comprising:

a high-frequency oscillator which includes a field generation layer and a spin injection layer, to which an external magnetic field and a bias current are applied;

a modulation electrode that applies a modulation voltage to the field generation layer; and

a modulation insulating layer that is interposed between the field generation layer and the modulation electrode.

2. The device according to claim 1, wherein

an interface between the field generation layer and the modulation insulating layer includes a protrusion structure.

3. The device according to claim 2, wherein the field generation layer comprises a main body having a plurality of sides, and the protrusion structure includes a protrusion that protrudes from one of the sides of the main body.

4. The device according to claim 1, wherein

the field generation layer comes into contact with the modulation insulating layer at two or more lateral sides of the field generation layer.

5. The device according to claim 4, wherein the modulation insulating layer is an oxide containing MgO.

6. The device according to claim 5, wherein

a portion of the field generation layer that is interfaced with the modulation insulating layer is an alloy containing Fe.

7. A magnetic recording head comprising:

a main magnetic pole that applies a recording magnetic field to a recording layer of a recording medium;

a write shield that faces the main magnetic pole with a write gap therebetween;

a recording coil that generates a magnetic field in the main magnetic pole;

a high-frequency oscillator that includes a field generation layer and a spin injection layer, and is disposed within the write gap between the main magnetic pole and the write shield;

a wiring that electrifies the high-frequency oscillator;

a modulation electrode that applies a modulation voltage to the field generation layer; and

a modulation insulating layer that is interposed between the field generation layer and the modulation electrode.

8. The head according to claim 7, wherein

the modulation insulating layer is an oxide containing MgO.

9. The head according to claim 8, wherein

a portion of the field generation layer that is interfaced with the modulation insulating layer is an alloy containing Fe.

10. The head according to claim 7, wherein

the interface between the field generation layer and the modulation insulating layer includes a protrusion structure.

11. The head according to claim 7, wherein

the field generation layer comes into contact with the modulation insulating layer at two or more lateral sides of the field generation layer.

12. The head according to claim 11, wherein

the field generation layer includes a main body having a plurality of sides, and a protrusion that protrudes from at one side of the main body, and

the number of protrusions in one side of the main body is greater than or equal to one and less than five.

13. The head according to claim 12, wherein

a ratio of a height of the protrusion to a size of the main body is greater than or equal to 0.3 and less than or equal to 1.

14. The head according to claim 7, further comprising:

a trailing shield that faces the main magnetic pole; and

side shields that are disposed on both sides of the main magnetic pole in a longitudinal direction and are magnetically separated from each other.

15. The head according to claim 14, wherein

the trailing shield and the modulation electrode are electrically connected to a modulation voltage circuit that creates a voltage between the modulation electrode and the trailing shield.

16. The head according to claim 14, wherein

the side shields and the modulation electrode are electrically connected to each other.

17. A disk drive comprising:

a disk-like recording medium;

a driving unit configured to rotate the recording medium; and

a magnetic recording head including

a main magnetic pole that applies a recording magnetic field to a recording layer of the recording medium;

a write shield that faces the main magnetic pole with a write gap therebetween;

a recording coil that generates a magnetic field in the main magnetic pole;

a high-frequency oscillator that includes a field generation layer and a spin injection layer, and is disposed within the write gap between the main magnetic pole and the write shield;

a wiring that electrifies the high-frequency oscillator;

a modulation electrode that applies a modulation voltage to the field generation layer; and

a modulation insulating layer that is interposed between the field generation layer and the modulation electrode.

18. The disk drive according to claim 17, wherein the magnetic recording head further comprises:

a trailing shield that faces the main magnetic pole; and

side shields that are disposed on both sides of the main magnetic pole in a longitudinal direction and are magnetically separated from each other.

19. The disk drive according to claim 18, wherein the side shields and the modulation electrode are electrically connected to each other.

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